Available online at www.sciencedirect.com
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ELSEVIER
Procedia Computer Science 16 (2013) 542 – 551
Procedia
Computer Science

Conference on Systems Engineering Research (CSER'13)
Eds.: C.J.J. Paredis, C. Bishop, D. Bodner, Georgia Institute of Technology, Atlanta, GA, March 19-22, 2013.

# METIS: Dependable Cooperative Systems for Public Safety[a]

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**Abstract**

Much, if not most, information needed to assess a crisis situation originates these days from cooperative sources such as the Internet and social networks. Public safety authorities face the challenge to compile this information of uncertain origin and quality in their situation understanding and response planning. Time matters: the integration of uncertain information needs to be done in a fast, goal-driven and ad-hoc manner.

Such situation understanding requires system support in the form of a dependable and cooperative system-of-systems: able to adapt semi-automatically to new situations and to improve the value of the information using built-in reasoning and awareness techniques. The METIS project researches such system support for public safety as a collaborative project of Dutch universities, knowledge institutes, and industry, using the maritime domain as case study. The METIS goal stretches the scope of system engineering, as the main requirements of ad-hoc adaptation and dependability contradict each other.

In this paper, we describe the METIS information architecture and highlight our four major research lines: (i) System architectures beneficial for dependability and adaptability; (ii) Application and system dependability ensured by embedded awareness; (iii) Ad-hoc system adaptability and goal-driven system reconfiguration; (iv) Integration and semantic alignment of various (natural language) information sources.



*Keywords*: complex adaptive systems; system reconfiguration; semantic alignment; quality of information; system-of-systems

## 1. Introduction

Situation awareness is crucial to make the right decisions and take appropriate actions in many application domains, including air traffic control, fleet management, and public safety and security. Current situation awareness support systems typically automatically handle most sensor information and present the same information to all operators using a geographical representation of the current situation. The handling of information from other

[a] This publication was supported by the Dutch national program COMMIT. The research work was carried out as part of the Metis project under the responsibility of the Embedded Systems Institute with Thales Nederland B.V. as the carrying industrial partner.
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doi:10.1016/j.procs.2013.01.057

sources, such as the Internet, is left to the operators.

The METIS[c] project has the objective to enable next-generation situation awareness support systems. METIS researches and develops techniques, architectures, and prototype support systems which provide operators with the information they need based on the current situation and their current task. The METIS project focuses on the combination of information from a wide variety of sensors and information sources, while dealing with the lack of control, the semantic heterogeneity, varying accuracy, timeliness, and trustworthiness, and the limitations to human perception and comprehension.

In this paper, we introduce situation awareness and show with an example the importance of incorporating a wide variety of information sources for accurate and complete situation awareness in Section 2. In Section 3, we examine situation awareness in depth and discuss system engineering concerns. In Section 4, we propose an architecture for situation awareness support systems. Derived from this architecture and the system engineering concerns, a number of the research challenges arise which we aim to address in the METIS project. In Section 5, we present these research challenges together with a few preliminary results. Section 6 then concludes this paper.

## 2. Situation awareness in the maritime domain, illustrated by a case of alleged weapons smuggling to Syria

Protecting coastal areas and shipping lanes is a daunting task for many governments: e.g. the Netherlands Coastguard employs 51 full-time equivalents who work 24/7 to continually maintain situation awareness for the Netherlands Exclusive Economic Zone; an area of 154.011 $km^2$. Vessels locations are monitored using AIS (Automatic Identification System) [10], supplemented by radar near to the coast. Use of AIS is mandatory for “class A” ships: international vessels above 300 gross tonnage, national vessels above 500 gross tonnage, and all passenger ships. Logged AIS recordings of vessels with “class A” ship borne mobile equipment over the period of June 1st, 2010 till July 1st , 2011 indicate that on average ~1377 vessels with “class A” ship borne mobile equipment are within the Netherlands Exclusive Economic Zone. Furthermore, every hour on average ~114 of these vessels leave or enter this zone (or turn off their AIS transmitter while moored – even when this is prohibited by the standard).

With such large number of vessels present in view, and considering the significant rate of change, system support is more than welcome. To support the operators in the maritime domain, cooperative systems for public safety strive to achieve following objectives:

- manage and support sea traffic, including emergency situations,
- protect the economic interests, including the exploitation of resources at sea such as oil and gas,
- enforce the law, i.e. prevent crime and protect assets,
- protect the environment, among others from pollution and against illegal fishing,
- control the border, ranging from customs to smuggling and illegal immigration, and
- defend the nation, including explosive ordnance disposal.

The following real-world case shows that these objectives -- notably the interdiction of weapons smuggling -- requires complex information processing and understanding of events as they are unfolding.

*April 2012*. The Syrian uprising, a violent internal conflict in Syria, is on-going for more than a year already. Public demonstrations across Syria began early 2011 and developed into a nationwide uprising. Protesters demanded the resignation of the president of Syria and the overthrow of his government. In response, the Syrian government increasingly deployed the Syrian Army to suppress protests, often with great violence. This caused the European Union to impose a weapons embargo for Syria.

*Thursday April 12, 2012*. Syrian activists have gotten news that a German vessel, destined for the Syrian harbor Tartus (or Tartous), could possibly have weapons and ammunition cargo on board for the Syrian armed forces. They warned the German owner of this vessel of this news, and also put out messages on Facebook [1], see e.g. Fig. 1.

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[c] In Greek mythology, Metis is an Oceanid and the Titaness of wisdom and deep thought.

*Friday, April 13, 2012*. All of a sudden, this vessel, Atlantic Cruiser changed course, heading for the Turkish harbor of Iskenderun instead the original destination Tartus, Syria. Then the ship stopped some 80 kilometers (50 miles) southwest of Tartus, sailing in circles for the next few hours [3], also Fig. 2.


Fig. 1. Facebook message [1] from Syrian Activists drawing attention to the Atlantic Cruiser.

*Saturday, April 14, 2012*. The German magazine DER SPIEGEL reported: “a German-owned freighter loaded with weapons from Iran was stopped on Friday near the Syrian port of Tartus in the Mediterranean Sea” [2]. Citing unnamed sources, the magazine reported that this vessel, the Atlantic Cruiser, “allegedly picked up heavy military equipment and munitions meant for Syrian’s regime from an Iranian freighter at the Djibouti port. The cargo, desperately needed reinforcements for Assad's crackdown on dissidents, was supposed to be unloaded on Friday.”
The same day, the vessel turned off its AIS (Automatic Identification System [10]) for hours at the time, making it harder to track the vessel’s position and course (AIS transmits amongst others GPS positions for collision avoidance, and can be received by on-shore receivers as well). This action of the ship's crew added to the suspicions about the vessel and its cargo.

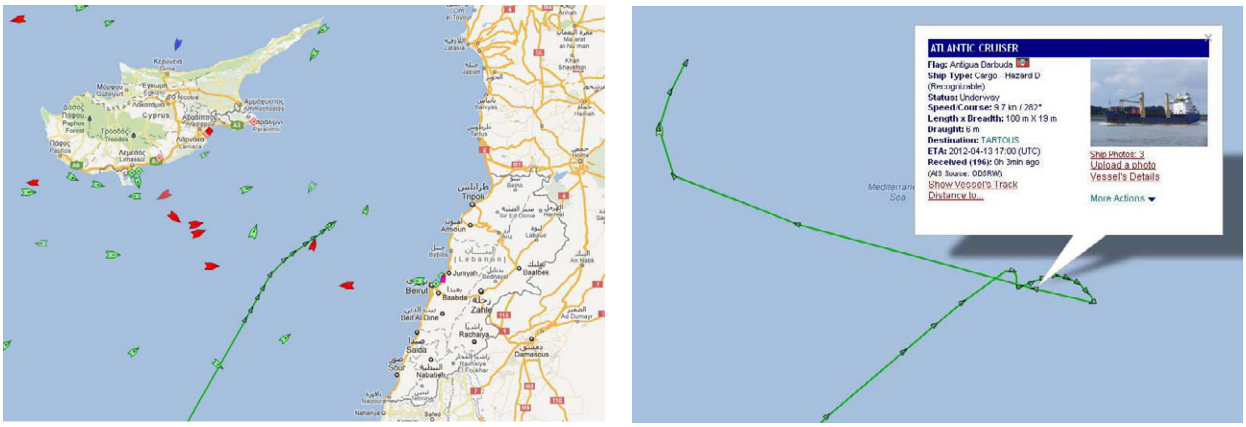


Fig. 2. Track of the Atlantic Cruiser. On the left, the normal track until April 12th, on the right a detail erratic track only a few hours later [3].

*Monday, April 16, 2012*. The owner, shipping company Bockspiegel Reederei GmbH, issued a press release [4] denying that the Atlantic Cruiser was carrying weapons: “*On Friday 13, 2012, the ship owner received an email with the allegation that the vessel would have on board arms and heavy weapons destined for Syria. The ship owner was requested not to call at Syrian ports; otherwise, the vessel would be attacked and sunk.*”

*Tuesday, April 17, 2012*. After sailing in circles for days, the Atlantic Cruiser arrived at the Turkish port of Iskenderun. Turkish authorities expressed intent to board the ship and inspect the cargo [5].

*Wednesday, April 25, 2012*. After several days of inspections, Turkish authorities have informed German government officials in Berlin that the German freight ship Atlantic Cruiser, is not carrying weapons bound for Syria after all. The ship's cargo is legal, and its loading papers have been correctly presented, officials say [6].

In summary, this tale of the “Atlantic cruiser” turned out to be a false alarm. Nonetheless, only days later (on Saturday April 28, 2012) Reuters [7] reported that Lebanese authorities did impound another vessel, the “Letfallah”. This vessel was found to carry a consignment of Libyan weapons including rocket-propelled grenades and heavy caliber ammunition. In face of such nation conflicts, (weapons) smuggling is to be expected, to be monitored, and to be intercepted whenever feasible. Situation awareness support systems can contribute significantly to the prevention or interception of such illegal activities.

## 3. Situation Awareness

Situation awareness strives to support coast guard or other government personnel in assessing current state of affairs. Following the seminal article by Endsley [8], we define situation awareness as follows: “Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.” This definition contains the following three hierarchical levels:

1. Perception of the elements (in the environment/in the current situation),
2. Comprehension of the current situation (situation understanding), and
3. Projection of future status.

The next sections introduce these three levels in more detail and relate them to the information flow and configuration control in the METIS project as shown in Fig. 3.

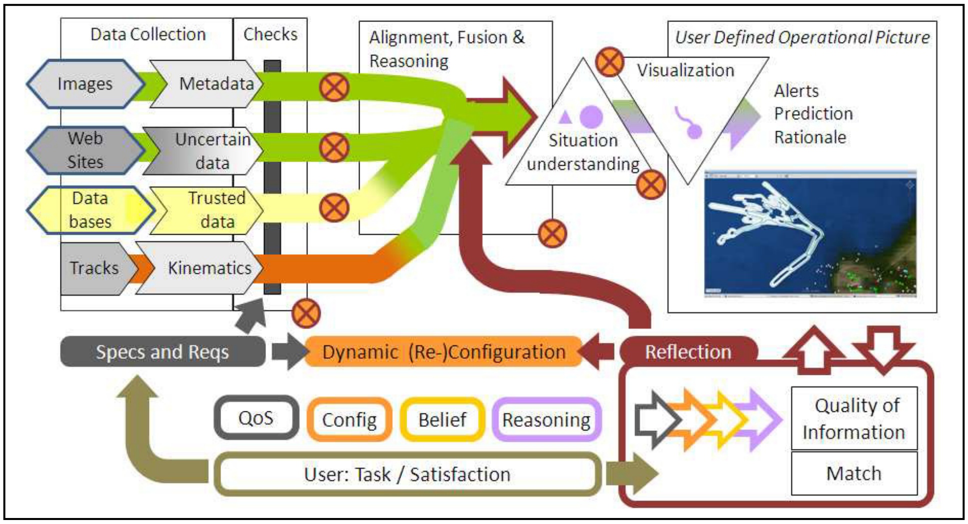


Fig. 3. Information flows in maritime situation awareness (upper half) and configuration/control objectives (lower half of graphic).

On the top half of this figure the information flows are shown, where information from various sources is selected, fused and reasoned about. Both sensor (kinematic) data as data of various qualified but also public sources may be used in the information fusion. Quality of information reasoning provides relative likelihoods of alternative rationalizations of acquired data sets.

The bottom half shows the introspection and reconfiguration options based on reflection and achieved quality of information levels. The various “valves” indicate (re)configuration options. Dynamic system reconfiguration aims to adapt the system on-the-fly to match operator priorities in balance with resource limitations.

### *3.1. Perception of the elements*

The (relevant) elements must be sensed at minimum to be able to perceive the current situation in the environment. The elements that need to be sensed for the maritime domain include not vessels but also unfavorable weather conditions, such as storms and hurricanes. Sensing is a continual process, occurring either directly by an operator or indirectly using sensors such as radar, sonar, and cameras. Information from multiple, possibly different, sensors may be fused to create a more complete view on the elements in the environment (see Fig. 3: Data Collection, Checks).

The information obtained from sensing can be combined with other, external information, e.g. from intelligence reports, databases, social media, and the Internet. Relevant information sources for the maritime domain may include the following:

- websites, such as Wikipedia and shipspotter.com,
- social media, such as Twitter and Facebook [1],
- databases, such as GrossTonnage.com and IHS Fairplay [9],
- blogs by experts and enthusiasts, and
- vessel sensor data, such as AISHub.net and MarineTraffic.com.

All these information sources may contribute background information of vessels, vessel types and characteristics, vessel crew, operators, owners, and up to the recent port-of-calls and voyages. The dynamic, near real-time nature of such external sources is nearly impossible to forego in today's fast changing world, hence the need for integration and comprehension technologies (see Fig. 3: Alignment, Fusion).

### *3.2. Comprehension of the current situation*

Situation awareness strives to comprehend the current situation. Most sources of information are typically not under control of the organizations which maintain situation awareness. Thus, system-of-systems challenges arise to integrate sources to comprehend the current situation. These integration challenges including semantic alignment of information, estimating and handling of trust in and accuracy of the provided information, and determining whether different pieces of information refer to the same element in the environment (see Fig. 3: Alignment, Fusion & Reasoning).

| | | | |
|---|---|---|---|
| Type | Cargo | 84% | 2 Sources (AIS, marinetraffic) |
| | Dry Cargo/Passenger | 16% | 1 Sources (Fairplay) |
| | OTHER | 01% | 0 Sources () |

Fig. 4. Alignment, comprehension, and likelihood assessment of various cargo types as reported by various information sources [16].

Fig. 4 shows the cargo types as reported by various information sources for a particular vessel. Here, the (cooperative) sensor AIS and website www.marinetraffic.com report this vessel as Cargo only, whereas the commercial database IHS Fairplay [9] reports this vessel as being a combined cargo/passenger vessel. Finally, part of likelihood assessment is to raise a (distinct) possibility is that not all sources may be right (or out-of-date) and that the vessel could be of yet another cargo type.

The trustworthiness of the source, in general, and the specific vessel information (web page) in particular, is needed to correctly judged and combined with other estimates to correctly judge likelihood of a vessel type. Even though such information is not 100% accurate, nor can be considered 100% trustworthy, ignoring these deprive an operator from valuable information. Situation comprehension in METIS context aims to provide the various alternative explanations of the current situation and their relative likelihood.

### 3.3. Projection of future status.

Finally, situation awareness makes a projection of the future status to predict possible course(s) of action. This projection enables informed decision making and appropriate action selection to pursue a set of, possibly conflicting, objectives. Projection may entail possible future travel trajectories (see Fig. 5), likelihood of collisions, incursion in forbidden areas, or even likelihood for intent to engage in illegal activities.

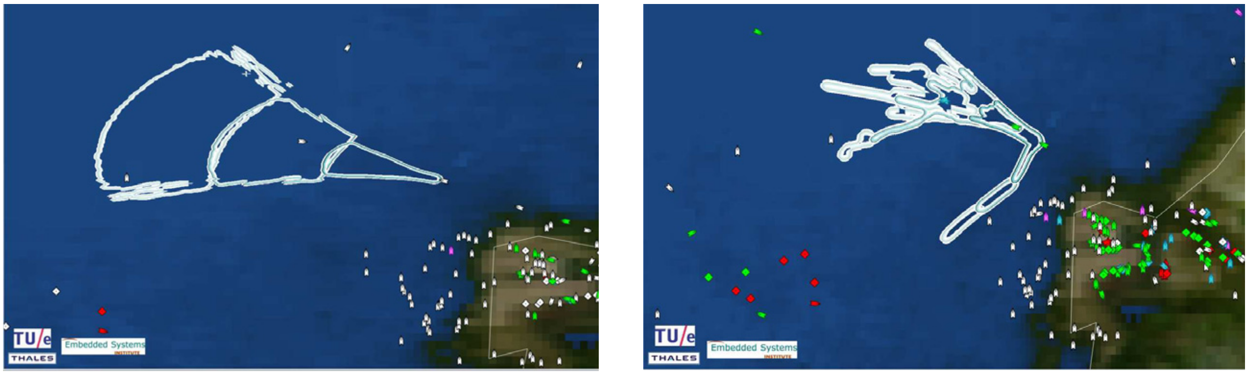

Fig. 5. Prediction of potential locations of a vessel within the next 10, 20, and 30 minutes ahead (on the left, purely on vessel motion capabilities, on the right based on historical travel patterns for this type of vessel) [14].

### 3.4. System configuration/control objectives

Besides the primary information and reasoning tasks, the configuration and control objectives of the system also have to be addressed. Situation awareness systems need to be highly adaptive: to the environment, to keep up with high arrival rates of vessels in special time periods, to keep up with higher than normal threat levels, and not in the least to keep up with ever changing tactics of the adversaries. For this, the system needs an internal reflection capability and a level of adaptation to cope with increased threat levels, or to incorporate new tactics or intelligence reports. In Fig. 2, the bottom half of the graphic shows this self-reflection and self-(re)configuration capability.

### 3.5. Situation awareness system engineering concerns

Engineering a situation awareness system implies integration of information from a variety of information sources that are not under the control of the system. System engineering concerns including the following:

1. Situation awareness systems must support operators to make sense of a situation. This requires not only an outcome, a state of knowledge, but also an explanation how that knowledge came about [11].
2. Every information source has its own semantics and structure. The information of different information sources must therefore be semantically aligned and represented in a common structure to enable reasoning with the combined information [12].
3. Many information sources are not targeted at systems but at humans. To process text written in natural language consistently, a system needs capabilities that exceed the current state-of-practice.
4. Every information source has its own evolution, i.e., its semantics, structure, and interface can change independently. A system must thus be able to detect and handle changes in the information sources.
5. The quality of information must be automatically estimated and propagated in all processing and reasoning steps, such that an operator can be provided the proper integrated information with its associated quality to ensure that appropriate decisions and actions will be taken [15].
6. Relating information to the elements in the environment (“symbol grounding”) is far from trivial [13]. Non-uniqueness of identifiers, such as names, require capabilities to reason that a vessel with name X which left Singapore harbor yesterday cannot enter the Rotterdam harbor today.

## 4. METIS Architecture

In this section, we describe the high-level structure and the design consideration for the blackboard and underlying information model as the pivotal element of the METIS system. The key considerations for the METIS architecture are the system-of-systems nature, the independent evolution of information sources, and the external environment dynamics including changes of adversary tactics need to be handled in a flexible, cost-effective way.

### *4.1. High-level structure*

The architectural view on the flow of information for the METIS system follows an earlier research system concept: the Poseidon Demonstrator [17]. Notably however, a strong increase in the number of information sources and variability therein is the challenge in the METIS context. Fig. 6 depicts the high-level structural elements in the METIS system. This figure has a strong focus on the new functionality that will be researched and developed in the METIS project. Existing functionality, such as developed in the predecessor Poseidon project [17], is supported by the blackboard style architecture but is shown explicitly in Fig. 6 for ease of understanding.

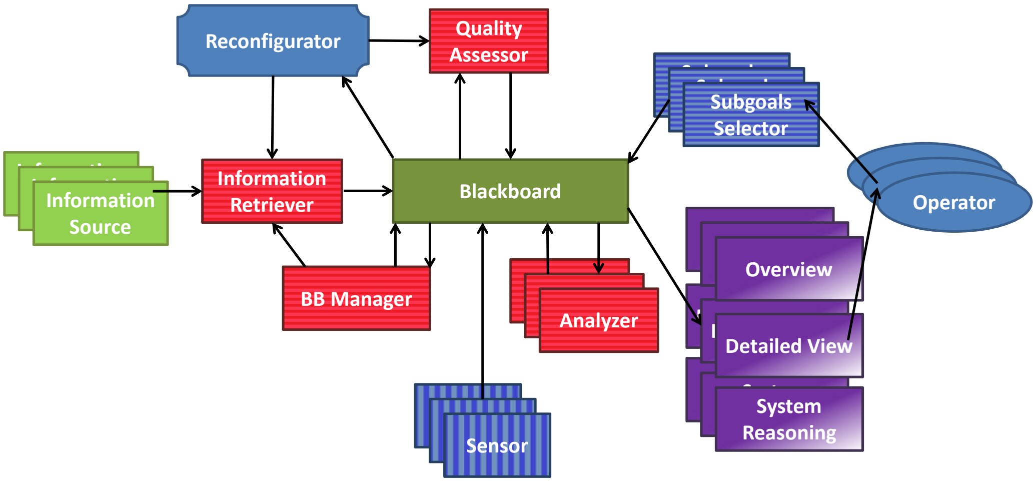


Fig. 6. High-level structural elements of the METIS system.

Below, we describe the high-level structural elements in Fig. 6:

- A **sensor** senses a part of the environment and pushes data of sensed environmental elements into the system.
- An **information source** provides background information or intelligence. Some parts of this information may be relevant for the awareness of the current situation.
- A **subgoals selector** is a part of the user interface of the METIS system. With a subgoals selector, each operator (explicitly or implicitly) specifies the current set of subgoals, for example, by specifying the current set of tasks or by selecting the currently relevant views.
- The **blackboard** provides storage for and enables reasoning with all data, information, and knowledge of the METIS system. Note that meta data, such as system health, available resources, and provenance, is included.
- An **analyzer** takes information from the blackboard and produces new information, using analysis techniques like inference, abstraction, and reasoning. For example, the Poseidon Demonstrator [17] contained analyzers to convert sensor to system tracks, to segment system tracks, to cluster vessel trajectories, to flag undesired vessel behavior, and to detect outliers in vessel trajectories.
- The **blackboard manager** ensures complete and up-to-date content on the blackboard. Among others, the blackboard manager should trigger information retrieval when new ships are detected by the sensors and handle the ageing of stored information either by updating, removing, or summarizing/compressing.

- The **information retriever** inserts externally available information into the METIS system. The information retriever has the following capabilities:
  1. generate multiple high-level queries for a specific information need,
  2. execute the currently best query, as determined by the reconfigurator,
  3. interpret the obtained results from the information sources,
  4. align the information both structurally and semantically, and
  5. put the information, and its provenance, onto the blackboard.
- The **quality assessor** determines the quality of both the information sources and the information on the blackboard. The quality of information sources is needed by the reconfigurator to determine the currently best query to be executed by the information retriever The quality of information on the blackboard is added as meta data to that information and include aspects such as trust, accuracy, and timeliness.
- The **reconfigurator** controls the 'configuration' of both the information retriever and the quality assessor. The reconfigurator uses information from the blackboard, such as the quality of the information sources and the subgoals, to determine the best configuration and query.
- The **visualisation** component has three kinds of views:
  1. An **overview** presents a view on a group of items, such as a map overlay containing the vessels in that area. An overview should present the information in such a way that an operator does not have to click each item individually to obtain situation awareness.
  2. A **detailed view** presents a view, e.g., a table, figure, text, or mind map, on a specific item, such as a vessel, person, or company.
  3. A **system reasoning** view presents a view on the system's reasoning process and its results. This view explains for example why the system considers a vessel a high risk item, why the system classified a vessel as ferry, and why the captain of a vessel is considered a criminal.

### *4.2. Blackboard design and information model*

For the design of the blackboard and the underlying information model that is the pivotal element of the METIS system, the following requirements apply:

- A single information model to re-present all information is needed such that reasoning on all pieces of information is possible, including relations between companies and persons, and criminal records of captains, crew members, and companies controlling vessels.
- Besides the maritime domain, other domains, such as justice and immigration, need to be supported as well. These other domains are needed to store information relevant for specific tasks, such as the detection of smuggling, pollution, and illegal fishing.
- The information model must be extendable. We must be able to add specific information to enable innovative and differentiating functionality.
- Although the information model might be larger than we (currently) need, the complexity needed to deal with should only be related to the actual parts in use.
- The information model should enable easy exchange of information with other systems.
- The information model should be able to capture meta data, such as provenance and uncertainty.

Based on these requirements, the National Information Exchange Model (NIEM) [18] was selected. The NIEM model is driven by the collective US government agencies to create an open, agreed-upon common standard for information exchange across many domains including justice, emergency management, intelligence, immigration and last but not least the maritime domain .

In METIS, the NIEM information standard provides the common information concepts. Using NIEM also ensures that METIS research result can be easily taken up by a wide range of cooperative public safety systems.

## 5. METIS Research Challenges

The main challenge of the METIS project is the systematic handling of uncertain information. To date, uncertainty is not addressed by support systems. Uncertain information sources are either ignored, when they are considered too uncertain, or included as being true, when considered to be above a threshold. The systematic handling of uncertain information affects all parts of the system. In the following subsections, we will discuss detailed challenges linked to specific parts, and their interfaces, of the system.

### *5.1. Information retrieval challenges*

Linking to external information sources is crucial for situation awareness. In METIS we focus on the following challenges with respect to information retrieval:

- How to automatically translate information needs into an executable set of queries, including processing steps that use the information sources to satisfy these needs?
- How to link information from human readable text to the structured, available information?
- How to reflect the quality and uncertainty in the structural and semantic alignment in the quality attributes of the aligned information?

### *5.2. Quality assessment challenges*

Properly valuating uncertain and possibly conflicting information help operators make sense of the situation. In METIS we focus on the following challenges in quality assessment:

- How to determine the quality attributes of information and information sources? In particular, how to determine whether information sources are independent?
- How to reason about the quality of information?
- How to assess and reason about the intentions of environmental elements, such as vessels and their crew?

### *5.3. Reconfiguration challenges*

Balancing system-internal activities with changes in the environment or monitored vessels provides for operator and system focus. In METIS we focus on the following reconfiguration challenges:

- How to ensure that an operator considers the system stable and understandable, while the system may need to continually reconfigure itself based on changes in the environment and in priorities of the many different kinds of system activities (updates of views, newly arriving vessels, background checks)?
- How do quality attributes of information and its sources, i.e., the input, relate to the quality of the system, i.e., the output, we want to optimize?
- How to reconfigure the information retriever to guarantee relevant information at a reasonable cost?
- How to reconfigure the quality assessor while guaranteeing high-quality and detailed estimates needed in the current situation?

### *5.4. Visualization challenges*

In METIS, we also address the challenge of visualizing uncertain information. First results have been achieved on visualizing uncertainty in positional, a.k.a. kinematic, data, using the principle of ‘blurring’ to visualize uncertainty [14]. Fig. 5 shows e.g. the boundaries of the area in which a vessel will probably be within 10, 20, and 30 minutes based on two different models.

In METIS we now have shifted focus to the following visualization challenges:

- How to visualize uncertainty in non-kinematic data such as vessel names, cargo, and destination? In this case, the principle of blurring doesn't seem appropriate since e.g. blurring names makes them unreadable.

- How to visualize system reasoning and the uncertainty therein (to support operator sense making [11])?

## 6. Conclusions

This paper has described the need for situation awareness in the maritime domain. It highlighted the research project METIS which addresses situation awareness support systems. This project has as focus the integral handling and assessment of disparate and uncertain information sources in an efficient and expedient manner for such systems. This objective requires the bundling of various disciplines: Semantic web technologies, information quality assessment and reasoning with uncertain information, reconfiguration and (re)planning, visualization, and information architectures for systems in context are all needed to create the next generation system-of-systems for situation awareness support. The METIS project has brought together these disciplines in a single project supported by real-world domain knowledge of the industrial partner Thales. The integration of results and synergy between research partners is expected to create novel insights that will drive industrially applicable innovation. The current architecture, as described in this paper, enables research activities in situation awareness with systems of systems as is proven by the Poseidon project [17] and by the first, preliminary research results of the Metis project on visualization and information quality, as reported in [14] and [15] respectively.

## Acknowledgement

This work resulted from numerous discussions with, and valuable contributions from METIS team members: Steffen Michels, Marina Velikova, RU; André Bonhof, Maurice Houtsma, Jan Laarhuis, Thales; Peter Novak, TU Delft; Roeland Scheepens, TU/e; Jesper Hoeksema, VU; and Pierre America, Michael Borth, David Watts, ESI.

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